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MANAGEMENT AND CONTROL OF UNSTEADY AND TURBULENT FLOWS

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The highlights of the conclusions from a wide range of experiments in transitioning, turbulent, separated and unsteady flow fields include the following:

The simultaneous generation of controlled phase-coupled plane TS waves and oblique waves was used to investigate the development of three-dimensional disturbances and mechanisms of transition in a Blasius boundary layer. From these experiments, the detuning of the fundamental/subharmonic resonance emerges as a primary candidate for the transition process under natural conditions.

Three-dimensional mappings of the Reynolds-stress-producing events in turbulent boundary layers over a range of Reynolds numbers and initial conditions have demonstrated that an integral-size of these dynamical motions scales better with outer variables as compared with inner variables. While the wall or inner layer is responsible for their initiation, the hierarchy of their scales in the log layer expands with Reynolds number according to this outer scaling.

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Real-time reactive control of a model unsteady separating flow was successfully implemented using a simple scheme for the detection of the separation.

The unsteady pressure and surface vorticity flux were documented over a range of non-dimensional pitch-up rates for a NACA0012 airfoil. The experiments revealed the time history for the generation of clockwise vorticity, in the region between the unsteady stagnation point and the leading edge of the airfoil, which is responsible for the formation of the dynamic stall vortex. These results have provided sound basis for the development of procedures for the management and control of the unsteady separating flow.

Model experiments over a bluff body were used to confirm our earlier conjecture that the unsteady bleed technique and internal acoustic forcing are synonyms for the same localized flow control technique and revealed some of its operative mechanisms. The same technique was effectively used in controlling the asymmetric system of vortices separating from a simple model of the forebody section of a flight vehicle. Proportional control of the side force was found to be feasible with this technique at low Reynolds numbers. The ability of the unsteady bleed technique to control the rate and direction of the coning-motion of a model at 60° angle of attack was also demonstrated.

I. CONTROLLED TRANSITIONING BOUNDARY LAYERS.

A. Resonant Growth of Three-Dimensional Modes in Transitioning Blasius Boundary Layers:

The simultaneous seeding of phase-coupled plane TS and oblique waves has been used to precipitate the first growth of 3-D modes in a Blasius boundary layer. This approach offers special advantages in that the initial seeding acts through a resonance mechanism so that only very weak initial amplitudes are necessary to reach energy saturation and transition. Additionally it overcomes the problems of spatial stationarity of three-dimensional structures which often plagues experiments relying on stochastic input. Under these controlled conditions, phase averaged velocity measurements in two space dimensions and time were used to reconstruct the dynamic motions of the staggered lambda structures that are dominant during subharmonic mode transition. These are presented as 3-D tracer particle distributions and sheets of vortex lines. Comparisons are made for different initial conditions set by varying the spanwise wave numbers of 3-D modes, as well as by controlled fundamental/subharmonic mode detuning (Corke and Mangano).

In these experiments subharmonic resonance was the mechanism for the growth of 3-D modes in a Blasius boundary layer. This involved an interaction between initial TS waves at a fundamental frequency, and pairs of subharmonic oblique waves of equal angles and opposite sign. These modes were produced by a spanwise array of heating wires placed near the critical layer. Through software control, the spanwise wave numbers of oblique modes was variable. The interaction was marked by a matching of phase velocities, resonant energy exchange and enhanced growth of the subharmonic mode leading eventually to large amplitudes and energy saturation. For different spanwise wave numbers, the maximum amplification rate was in good agreement with predictions arising from an H-type mechanism.

With the growth of the subharmonic mode, other nonlinear 3-D interacted modes were produced. Their streamwise and spanwise wave numbers had been experimentally verified. Owing to the spatial stationarity afforded by the 3-D mode seeding, phase averaging brought out the coherent motions associated with the staggered lambda structures observed in flow visualization. The eventual saturation of the subharmonic mode was marked by a loss of precise phase locking between the subharmonic mode and higher interacted modes. This initially stemmed from fundamental mode side bands which acted through sum and difference interactions with the subharmonic to produce low frequency broad band modes. Downstream, these modes interacted with the subharmonic to gradually fill the spectrum. With low initial amplitudes, this is expected to be the chief scenario for the natural growth of three-dimensionality and transition to turbulence in most boundary-layer flows.

B. Effect of Controlled Resonant Interactions and Model Detuning on Turbulent Transition in Boundary Layers:

The simultaneous generation of phase-coupled plane TS waves and oblique waves with respective wave numbers (α_1, 0) and (α_2, β_1), (α_2, β_2) are used to study the growth of three-dimensional disturbances in a Blasius boundary layer. This was accomplished using a computer controlled array of line heaters to produce time periodic, spanwise-phase-varying velocity perturbations. Conditions for subharmonic resonance with a TS mode (α, 0) and symmetric oblique modes ($\alpha/2, +\beta$) and ($\alpha/2$, $-\beta$) have been fully documented for different streamwise and spanwise wave numbers. Of special interest was the growth of higher harmonic modes including ($3/2\alpha$, $\pm\beta$), ($5/2\alpha$, $\pm\beta$), ($\alpha, \pm 2\beta$), and (0, $\pm 2\beta$). Contrasted with these are nonlinear interactions produced by initial nonfundamental/subharmonic modes. Comparisons point to the role of detuned modes as a mechanism for energy saturation and spectral filling associated with laminar to turbulent transition (Corke 1989).

We have successfully been able to promote the resonant interaction between plane TS waves and 3-D oblique waves with equal and opposite wave angles. This resulted in *rapid nonlinear growth of* 3-D *modes with a minimum* amount of disturbance input. We have verified the amplification rate dependence of different spanwise wave numbers of the 3-D modes, as well as the lack of the need for precise fundamental/subharmonic mode tuning for resonance to occur. These are all in agreement with the theoretical predictions of Herbert (1983, 1988). Utilizing low initial amplitudes of the primary modes we documented the basic features of the flow from a time averaged and phase averages sense. These showed a spanwise character which was commensurate with the initially seeded subharmonic mode spanwise wave number and spanwise wave numbers of interacted modes. The basic structure consisted of inclined counter rotating circulations which alternately pumped fluid away from and towards the wall. Coincident with these regions were upward and downward tipped vortex loops. Although these vortex loops were a prominent feature of the flow, the level of vorticity associated with them was relatively small. The maximum vorticity was carried by the subharmonic oblique modes, evenly distributed in all vorticity components. Even at energy saturation, the level of these was almost 10 times smaller than the mean profile ω_Z. In light of this, there was no mechanism for the growth of high shear layers which would contribute to the transition to turbulence. Rather transition occurs through a gradual detuning of the fundamental/subharmonic resonance which can spread, through numerous sum and difference interactions, energy to a broad band of modes leading to energy saturation and a smooth transition to a turbulent state. Any approach towards predicting or controlling this process under natural conditions with random mode seeding from background disturbances must take into account this scenario.

II. TURBULENT BOUNDARY LAYER STRUCTURE AND CONTROL AND RELATION BETWEEN TRANSITIONING AND TURBULENT BOUNDARY LAYERS

A. Reynolds-number Effect and Symmetry of Coherent Structures in a Turbulent Boundary Layer:

An experimental investigation was undertaken which focused on the study of three-dimensional large-scale coherent motions associated with the Reynolds-stress production process in the wall layer of a turbulent boundary layer. This work expands on previous investigations (Guezennec 1985 and Wark 1988) from which two major questions stemmed. The first of which concerns the effect of Reynolds number on the hierarchy of scales involved in the Reynolds-stress production process and the second concerns the symmetry of the instantaneous structures and how it is affected by Reynolds number.

It is clear from these results that the ensemble-averaged structures associated with the wall-shear velocity detection scheme scale better with outer variables as compared with inner variables for the two Reynolds numbers investigated. The scaling for several experiments performed at IIT and for the direct numerical simulations of NASA/Ames clearly, demonstrates that the integral length scale for turbulence production in the log layer scales better with outer variables as compared with inner variables.

An appreciable fraction of the Reynolds-stress-producing events have been shown to be symmetric with the smaller-scale events being more symmetric than the larger-scale events. Events with a given spanwise size (z^+) occur symmetrically more often for the higher Reynolds number as compared with the lower Reynolds number.

B. Relation Between Outer Structures and Wall-Layers Events in Boundary Layers With and Without Manipulation:

The scaling of structures related to high Reynolds stress production in turbulent boundary layers was investigated over a wide range of regular and drag reducing conditions. Consistent with the development of their integral size, which is proportional to the outer scale, a model for the growth of these vortical structures based on joining of neighboring pairs was conjectured from the measurements.

Five significant conclusions may be reached from our results: 1) The wall layer is responsible for the initiation of coherent structures of all sizes; 2) a hierarchy of similar scales exists for high Reynolds numbers; 3) the integral scale of the hierarchy is proportional to the outer scale of the boundary layer; 4) while the development of the

smaller scales of the hierarchy is very rapid a redevelopment of the full hierarchy after manipulation is gradual; and 5) the larger scales of the hierarchy (so called "outer scales") play only a partial role in the wall process since the smaller scales of the hierarchy appear to be incipiently generated and self sustained.

A model was proposed by Nagib et al. (1987) in an attempt to bring together some of these ideas. A big unanswered question in that model is related to the development of the larger scales. However, the model postulated that the ejection (Q2 or T-) events are related to upright lambda structures and that the sweep (Q4 or T+) events are associated with inverted lambda structures. A process similar to that occurring during transition may continue indefinitely in the wall region of turbulent boundary layers. The rollers (Townsend's typical eddies) are the legs of these vortical structures.

In a model based on a hierarchy of geometrically similar eddies, Perry and Chong (1982), propose "vortex pairing of two eddies in one hierarchy to form an eddy in the next hierarchy", as one possible mechanism for the growth of structures (e.g., lambda or hairpin). Later Perry et al. (1986) conclude that the work of Acarlar and Smith (1987) had "shown that the speculated pairing process does in fact occur, at least for hairpin-type vortices" artificially introduced into laminar boundary layers. The interaction documented by Acarlar and Smith (1987) is of eddies occurring sequentially in space and therefore is of a similar type to the well understood "pairing" in free-shear flows. A model for the growth of eddies within the hierarchy, more consistent with the original ideas of Perry and Chong (1982), was proposed by Wark and Nagib (1990). Joining of neighboring structures, and destruction of their adjoining legs through cancellation of opposite sign vorticity, would lead to the required doubling of the transverse scale. Similar interaction between eddies of dissimilar size can lead to the non-symmetric structures found in computational results at the lower Reynolds numbers. A similar scenario can also be drawn for the inverted (sweep) events.

One inconsistency between our ideas and those of Perry et al. (1982 & 1986) is the inclination of the dominant vortical structures. They require a 45 degree inclination based on earlier flow visualization while a much shallower angle is clearly revealed by our measurements at high Reynolds numbers. The "neck" of the lambda (or hairpin) structures is more likely to be at the 45 degree angle and may be more visible and active at lower Reynolds numbers.

While the frequency of events producing large Reynolds stresses in the wall region scales with inner variables of the boundary layer, an integral measure of the hierarchy of scales involved is found to be proportional to the outer scales. This conclusion is based on analysis of the experimental data from IIT and computational data from NASA-Ames using the same measure of the scales over one decade of Reynolds number variation. Experiments downstream of drag reducing manipulator blades and measurements of the distribution of scales within the hierarchy confirm this result and suggest the existence of a

rapid or geometric growth mechanism for the coherent vortical structures (Wark and Nagib, 1991).

Further evidence was obtained in support of the suppression mechanism as being the key one in the understanding of the manipulation by flat devices extending across the boundary layer parallel to the wall. Detailed examination of the structures connected to the turbulence production process, without and with manipulators of different arrangements, does not reveal breakup by the blades of larger eddies into smaller one, as suggested by the designation LEBU devices.

C. Conditioned Flow-Visualization of Structures Associated with the Reynolds-Stress Production Process in a Turbulent Boundary Layer:

Photographic records of various laser sheet cuts in turbulent boundary layers visualized using a smoke-wire were obtained for the Reynolds number range of $1500 < Re_\theta < 4000$. The smoke wire was positioned parallel to the boundary at a height of $50 < y^+ < 300$. High speed still and movie records of the y^+ - z^+ plane, conditioned on the occurrence of a high or low shear-stress event, depict the instantaneous shape and evolution of structures associated with Reynolds-stress production. Simultaneous records of the shear-stress signal at the wall beneath the photographic image revealed the relation between structures and their signature at the wall. The conditions were chosen to overlap with the recent detailed 3-D mappings obtained experimentally here at IIT and with the computational results from NASA-Ames. The present visualization experiments use the same shear-stress detection procedure as that for the mapping experiments. Among other characteristics revealed by the visualization are the shallow angle of inclination, with respect to the wall, and the symmetry of the structures.

D. Effects of Transition on the Reynolds-Stress Producing Events in a Turbulent Boundary Layer:

An experimental investigation was carried out to investigate the effects of transition conditions on the development of coherent structures associated with the Reynolds-stress production process in turbulent boundary layers. Two types of transition conditions were investigated: i) a sandpaper trip, which has been used in our laboratory over the past several years, and ii) a "fence-type" trip. Both conditions were seen to produce an equilibrium turbulent boundary layer, by "conventional" standards, over the Reynolds numbers investigated. Measurements of the streamwise velocity were made over a Reynolds number range of $1800 < Re_\theta < 6000$ for $15 \leq y^+ \leq 220$ to study various statistics resulting from the u-level and VITA detection schemes. A two-dimensional sampling grid was used to investigate the effect of the two transition conditions upon an "integral-scale"

measure of the ensemble-averaged structure associated with a wall-shear stress detection scheme. The results suggest that the frequency of occurrence of u-level and VITA events are insensitive to transition conditions; whereas, a small change is seen regarding the "integral-scale" of the ensemble-averaged structure associated with the wall-shear stress detection scheme. In addition, a clear Reynolds-number effect on u-level detection frequency is seen for Re_θ less than approximately 2700.

No effect on the frequency of u-level and VITA events was observed between the two transition conditions investigated over the range $1800 < Re_\theta < 6000$. Also the probability distribution of time between ejections is similar between the two transition conditions. A small effect on the spanwise scale of the ensemble-averaged structure associated with wall shear-stress detected events was seen between the two transition conditions. The "fence-type" trip had a given spanwise periodic scale which did not manifest itself in the results for the ensemble-averaged structures. This suggests that the integral scale Λ_z is an inherent characteristic of turbulent boundary layers.

An interesting observation was seen for the u-level detection results. For the lowest Re_θ values investigated, the non-dimensional frequency of occurrence was significantly higher as compared with the results at the higher Re_θ values. At $y^+ = 15$ the non-dimensional frequency collapsed well for $Re_\theta >$ approximately 2700. For $Re_\theta < 2700$ a clear effect was observed: this result was independent of transition condition.

III. MANAGEMENT OF UNSTEADY AND THREE-DIMENSIONAL SEPARATED FLOWS

A. The Detection of Flow State in an Unsteady Separated Flow:

A model experiment that exhibits some of the characteristics of the leading-edge separation over unsteady airfoils was conducted, and a simple, non-intrusive technique for detection of flow reversal was developed. The unsteady separation introduced in a turbulent boundary layer, by the motion of a spanwise flap into the flow, was investigated for a range of Reynolds number and flap angular velocities. Smoke-wire flow visualization, measurements of the time-varying flow direction at various locations behind the flap, and wall pressure data were used to characterize and document the steady as well as unsteady separation. Ensemble-averaged static-pressure data measured for a representative set of parameters were used to formulate different criteria to identify a change in flow direction at different streamwise locations. These criteria were tested by "playing back" time-series data of the wall pressure covering a range of Reynolds numbers and flap rise times. Phase-conditioned flow-direction measurements were used as the reference to evaluate the

performance of these criteria. Flap-drop experiments representing unsteady flow reattachment, as well as combined flap motions were also examined. Two of the criteria formulated in this study show good promise for use as flow-state identifiers in the active control of unsteady separated flows (Ramiz and Acharya, 1991).

B. The Reactive Control of an Unsteady Separating Flow:

Experiments were carried out to attempt the real-time, reactive control of a model unsteady separating flow that was dominated by the evolution and movement of a strong vortex. The results underscore the fact that measurements of pressure at a single location can be used to sense the flow condition, as well as to activate a flow controller to modify the extent of the separated region. The unsteady separation was introduced in the flow over a flat plate by a spanwise flap moving into the flow. The wall pressure at a chosen control location was monitored during the deployment of the flap, to determine when flow reversal associated with the unsteady separation occurred. When the prescribed criterion was met, a pulsed-jet flow controller was activated to modify the separated region by reducing its mean reattachment length.

These experiments demonstrate the feasibility of real-time, reactive control of a generic unsteady separating flow, using simple but effective techniques. While some questions still need to be addressed, the basic approach is viable. A significant feature of this model flow is that the unsteady separation process is dominated by the evolution and movement of a strong vortex. A similar approach, which uses the signature of wall pressure at appropriate locations to detect some characteristic feature of the flow, should work for other unsteady separating flows, which are similarly characterized by the appearance and movement of a strong vortex.

C. Evolution of the Unsteady Pressure Field and Vorticity Production of a Pitching Airfoil:

The unsteady pressure field and the accompanying variations in the flux of spanwise vorticity from the surface were measured over a range of dimensionless pitch rates, for a two-dimensional, NACA 0012 airfoil model, undergoing a single pitch-up motion. The results were examined to identify the mechanisms that play key roles in the initiation, development, growth and movement of the dynamic-stall vortex. The unsteady pressure distribution over the airfoil was dominated by three features, whose emergence and evolution were used to distinguish between two classes of behavior, corresponding to low and high pitch rates. Further, it was found that the flux of vorticity from the surface originated primarily from five concentrated regions or sources, the majority of which were located over the forward portion of the airfoil surface. The behavior of vorticity flux from these sources was related to the interacting mechanisms responsible for the development of

the flow field. The change of these features in the pressure and surface vorticity flux variations with pitch rate have been described (Metwally and Acharya, 1991).

Measurements of the pressure distribution over the airfoil model and the variations in the flux of surface vorticity during the pitch up have helped bring about an increased understanding of the mechanisms that interact to control the evolution of this complex unsteady flow. A significant feature of these data was the spatial resolution in the forward portion of the airfoil surface, that allowed the details of these variations to be captured. The process by which the dynamic-stall vortex forms, grows and detaches from the suction surface has been identified. The results have also provided a sound basis for the development of procedures that might be adopted in a successful unsteady-flow management system. The requirements for such procedures are being investigated.

D. Mechanisms of Flow Control with the Unsteady Bleed Technique:

Experiments were conducted on a right-circular cylinder with a single unsteady bleed slot aligned along the axis of the cylinder (Williams, et al. 1991b). The effects of forcing frequency, forcing amplitude and slot location on the azimuthal pressure distribution were studied. The results suggest that a strong vortical structure forms near the unsteady bleed slot when the slot location is upstream of the boundary layer separation point. The structure is unsteady, since it is created by the unsteady forcing. The "vortex" generates a sizeable pressure spike (C_p = -3.0) in the time-averaged pressure field immediately downstream of the slot. In addition to the pressure spike, the boundary layer separation location moves farther downstream when the forcing is activated. Delay of the separation is believed to be a result of enhancing the Kelvin-Helmholtz instability. When forcing is applied in a quiescent wind tunnel, a weak low-pressure region forms near the slot that is purely the result of the second-order streaming effect.

The unsteady bleed technique and internal acoustic forcing are synonyms for the same localized flow control technique. Measurements of the sound pressure level and the r.m.s. velocity amplitude at the slot have shown that the dominant disturbance is associated with the "pumping" of fluid by the loudspeaker, not the acoustic wave.

Pressure distributions obtained around the cylinder show three independent mechanisms are present that modify the flow. The weakest is the "streaming" effect created by the rectification of the unsteady pressure field at the bleed slot. This is likely to be insignificant in most cases unless the forcing amplitude is very strong. The second mechanism is a strong "vortex-like" disturbance created by the interaction between the forcing flow and the flow around the body. This resulted in a very strong pressure spike immediately downstream of the slot. The third mechanism is the enhancement of the Kelvin-Helmholtz instability in the separating shear layer, which produced a change in the pressure field slightly weaker than the pressure spike.

The latter two mechanisms will likely be present on all types of bodies in which the unsteady bleed technique is applied. The relative importance of the two will depend on the details of the forcing configuration, such as the location of the bleed slot and the forcing amplitude.

E. Control of Asymmetric Vortices Around a Cone-Cylinder Geometry with Unsteady Base Bleed:

The system of vortices that separate from the forebodies of aircraft and missiles at high angles of attack has long been recognized as a significant contributor to the aerodynamic loading on the vehicle. Strong yaw moments are created which can overwhelm the control surfaces causing the vehicle to lose control. For example, the unpredictable trajectories of missiles launched at high angles of attack are related to the forces generated by the forebody vortices.

The asymmetric vortices can be controlled to some extent with external appendages such as strakes and fins; however, a more efficient way of managing the side forces would be to control the strength and configuration of the separating vortices by modifying their formation process. The unsteady base bleed technique is a new method that can control the formation of the Karman vortex street behind a right circular cylinder (Williams and Amato) without the use of external appendages. In this set of experiments it has been shown that the unsteady base bleed can also be used to modify the flow around a cone-cylinder model at high angles of attack (Williams and Papazian).

The unsteady base bleed technique provides a mechanism by which momentum can be added to the flow, while simultaneously reducing the mean pressure at the exit of the control port. This technique is shown to be useful for controlling the flow around a cone-cylinder model. In particular, the naturally occurring asymmetric vortex configuration can be made symmetric. The reduction of asymmetry depends on a combination of momentum addition and low pressure at the control ports. The control effect is not particularly sensitive to the specific frequency of forcing, but is dependent on the amplitude of the velocity at the exit of the control port.

It has been shown that the unsteady base bleed technique is effective in controlling the asymmetric system of vortices separating from the cone-cylinder geometry representing the forebody section of a flight vehicle. Quantitative measurements indicate that the strong tip vortex can be eliminated, and the flow field can be made nearly symmetric if the level of forcing is high enough. Investigations into the control mechanism suggest that the it is related to changes in the mean flow brought about by the time-averaged components of momentum and pressure associated with the nonlinear effects of the forcing. This

highlights a novel feature of the unsteady base bleed technique; namely, that it simultaneously lowers the exit pressure while adding mom ,ntum to the flow.

F. Proportional Control of Asymmetric Forebody Vortices with the Unsteady Bleed Technique:

The importance of the forebody vortex system to the dynamics of aircraft and missiles at high angles of attack has been demonstrated by numerous investigators. For angles of attack in the range of 40° to 60° a steady system of vortices usually separate from the body in an asymmetric configuration. These vortices create side forces which may be strong enough to overwhelm the control surfaces. Interaction of these vortices with the wings, fuselage and tail can lead to wing rock, spin and tumbling of the vehicle.

Methods for controlling the forebody vortex system include rounding the tip, strakes, steady and unsteady blowing. The unsteady base bleed technique was introduced recently (Williams et al., 1989) as a way to eliminate the forebody vortices and restore symmetry to the flow. The primary advantages of this technique are that it does not require any external appendages which introduce additional drag, it can be turned on and off as needed, and no continuous supply of bleed fluid is required. Currently, we are attempting to extend the unsteady bleed technique to gain complete control over the vortex system. By "complete" we mean to control the position and strength of the vortices in such a way that they can be used to help maneuver the vehicle rather than interfere with the control surfaces. For example, yaw moments could be increased during turns at high angle of attack with proper vortex control.

Managing the forebody vortex system will require being able to flip the asymmetric vortices from one side of the forebody to the other. Proportional control is also needed to maneuver correctly, so the strength of the vortices must also be variable.

In conclusion, the data demonstrates that proportional control over the side force is fea ,le with the unsteady bleed technique. The effectiveness of the control is dependent on angle of attack. We suspect that this is an indication that the forcing holes may need to be relocated, depending on α. However, when the model was near 55° angle of attack it was possible to change the sign of the sectional side force coefficient.

Wind tunnel experiments have been conducted to demonstrate the ability of the unsteady bleed technique to control the rate and direction of coning-motion rotation with a cone-cylinder model at 60° angle of attack.

IV. SCANNING LASER ANEMOMETER AND OTHER OPTICAL TECHNIQUES

A preliminary investigation of a fast scanning LDV system in air was carried out. The laser system employs a 2 mW Helium-Neon dual-beam laser in forward-scatter configuration. A unique feature of this scanning system is that it does not contain any mechanically moving parts; rather, scanning of the laser beams is achieved using Acousto-Optical Devices, or Bragg cells. Experiments show that Acousto-Optical Devices can be used successfully as optical scanners to scan laser beams over a scan range from 5 to 10 cm. In addition, the existence of a fringe pattern, during scanning, has been verified both visually and from monitoring the Photo-Multiplier output on the oscilloscope. Additional work is required to bring this system to practical applications.

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